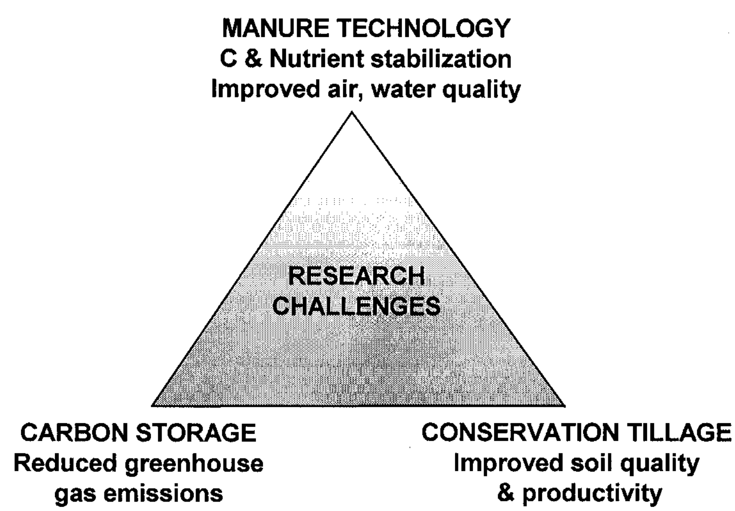
Animal Residual Treatment and Soil and Water Resource Management

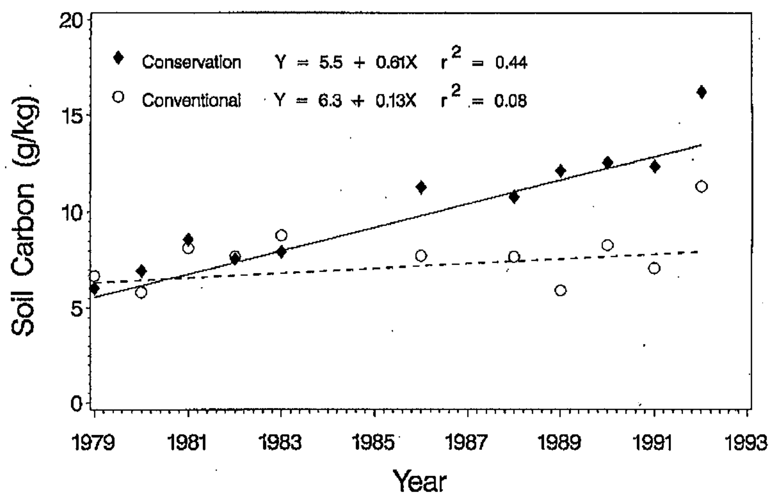
Patrick G. Hunt and Matias B. Vanotti

USDA-ARS
Coastal Plains Research Center
Florence, South Carolina

Our approach to animal residuals (manure) has been to enhance the potential for effective and affordable treatment and ecosystem benefit. Needless to say that simple flushing, holding, and dumping will not meet these objectives. Modern animal production is a very sophisticated business, and the treatment of its residuals will also have to be sophisticated. Direct application of municipal waste treatment technologies will not suffice. There are many aspects of animal residuals such as waste characteristics, operator involvement, regulations, and fiscal resources that are distinctly different. Nonetheless, adaption of municipal technologies is likely to be the basis from whence the appropriate technologies can emerge. In addition, as these technologies are adapted and new ones emerge, it will be most effective if residuals can be used to solve other existing problems.



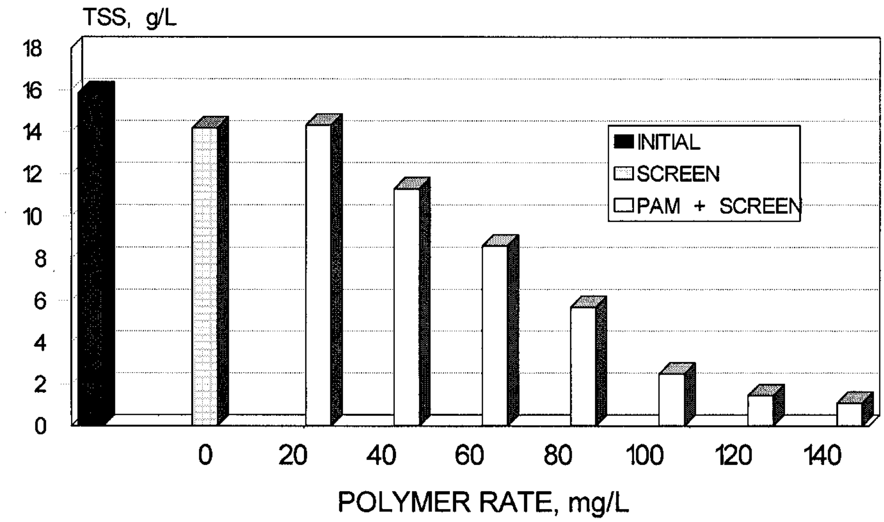
We are addressing an approach that will allow treatment of the animal residuals and mitigation of two significant ecological and agricultural problems - soil productivity and carbon dioxide sequestration (Fig. 1). Our focus has been on swine and dairy where flush systems generate wastewater. In swine and dairy operations, we need improved solids and liquid separation technologies so the solids fraction can be collected and transported to central facilities for efficient processing and marketing. In these facilities, the residuals can be blended into balanced and mildly recalcitrant forms that can be applied to soils at rates that will permit accelerated accumulation of soil organic matter with its associated enhancements of soil productivity. If the residuals were applied subsurface in conservation tillage, additional benefits would accrue. Conservation tillage alone has been shown to increase soil carbon even in soil and ecosystems noted for their low soil organic carbon contents. Hunt et al. (1996) more than doubled the carbon content of a sandy southeastern soil after 14 years of conservation tillage, and the improvements in soil quality allowed them to successfully use strict no-till in subsequent years (Fig. 2). Addition of recalcitrant forms of animal residual to the subsoils of these and other soils would not only accelerate enhancements in crop productivity (Frederick and Bauer, 1996; Frederick et al., 1998), it would very likely dramatically increase soil carbon. Such increases have even been reported for soil that received animal residuals for over 150 years at the Rothemsted experiment station (Jenkinson, 1991).



Accomplishing effective animal residual management along with enhanced carbon sequestration and soil productivity will be affected by an array of public policies including credits for carbon sequestration and conservation tillage. However, the most important policy will be a commitment to solve the animal residual problems in a win-win manner and save animal production in the USA. The remainder of this paper will address some of the initial technologies that could be the part of the base for such solutions.

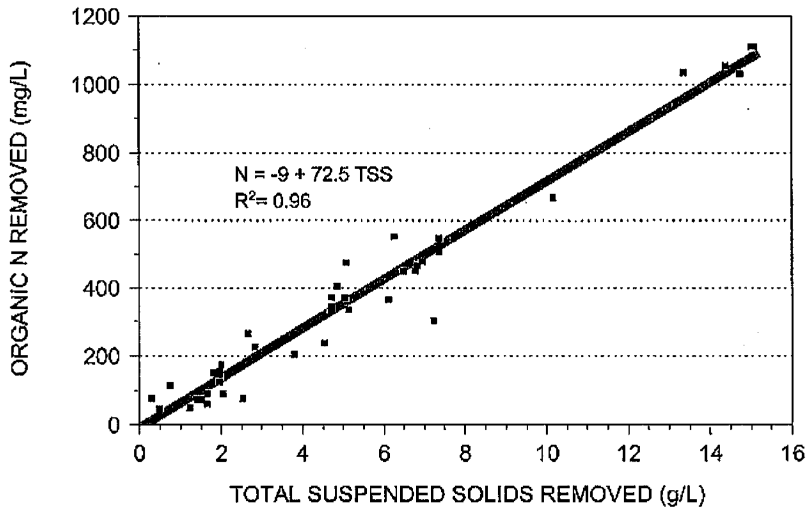
Modern swine and dairy production typically utilizes some type of water conveyance system to move the waste from the confinement house. Flushing systems are preferred because of their simplicity, economy, and lower ammonia emissions compared to manure scrapping systems (Barker and Driggers, 1981; Sievers, 1989). Flushing is done at rates that vary from 500 to 2000 L per 1000 kg live mass per day. This high dilution results in wastewaters that have very low solids concentrations, often in the range of 0.2 to 1.5% total solids content. Although substantial amounts of carbon (C) and nutrients can be removed from industrial and municipal wastewaters by solids-liquid separation using dewatering presses and screens, most of the organic nutrients in swine wastewater effluents are contained in fine suspended particles that are not separated by available mechanical separators (Hill and Tollner, 1980). Separation of suspended solids from animal wastewater using screens and presses is very inefficient (5 to 15%) and requires chemical coagulation to bind together the small particles of solids into larger clumps (Sievers et al., 1994). Previous work (Loehr, 1973) with inorganic flocculants such as alum or calcium and iron salts showed that even though these compounds are very effective, they have limited application for animal wastewater treatment because of the large amounts of material needed and the large quantity of additional solids generated.

Our evaluation of cationic, anionic, and neutral polyacrylamides (PAM) showed that the cationic type is very effective and probably a better option than alum for separating solids and nutrients from flushed swine wastewater (Vanotti and Hunt, 2000). Within the cationic PAM type, materials that had moderate-charge density (20%) were more effective than polymers with higher charge density. The reaction of PAM with the wastewater was fast and produced large, dark-brown flocs that rapidly settled out of the matrix wastewater, leaving a remarkably clear supernatant (Fig. 3).



The flocs were large enough to be effectively retained by a 1-mm opening screen. High TSS removal efficiencies (> 90%) were obtained with PAM rates of 26 and 79 mg/L applied to samples containing 1.5 and 4.1 g TSS/L, respectively. At these optimum rates, the polymer usage rate was about 2.0% of the TSS produced. For a typical feeder-to-finish operation, the calculated chemical cost per finished pig is $2.79 (Vanotti and Hunt, 2000). Flocculation and separation of suspended solids in turn significantly decreased COD and organic nutrient concentration in the treated effluent. Removal efficiency of organic N and P followed approximately a 1:1 relationship with removal efficiency of TSS. Our results indicate that PAM polymers have a potential for efficient separation of manure solids, COD, and nutrients from flushed swine operations. Large COD removal has direct implication on odor emissions from existing lagoons. The proposed technology also provides an attractive alternative to existing liquid manure management methods. It, thus, promotes the transportation of nutrients from nutrient-rich to nutrient-deficient areas and expands options for environmentally sound and sustainable swine production.

After the initial separation of liquids and solids, additional separation of liquids and solids is necessary before effective and economical transport can be accomplished. Many methods are available, and they range in sophistication. Two methods that represent the passive and high tech, respectively, are the Deskins Sand Filters (David Deskins, Alexandria, IN) and the Ecoliz filter press. (Elf Atochem, Paris, France). Additionally, Super Soil Systems USA (Lew Fetterman, Clinton, NC) has an interesting electrical stabilization unit which has promise for improved solid waste handling and pathogen reduction.



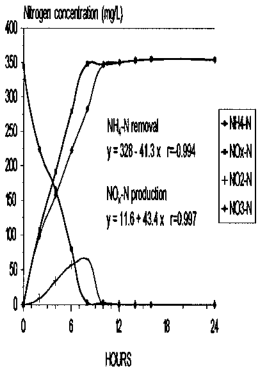
Although nearly all of the organic N and P were removed with the TSS, an equal amount still remained in the soluble fraction (Fig. 4). Thus, after the solids are removed, the wastewater must be treated to capture and/or transform the nutrients in the soluble fraction. One of the primary transformations is the conversion of ammonia nitrogen to nitrate nitrogen via microbial nitrification. Biological removal of N through the process of nitrification and denitrification is regarded as the most efficient and economically feasible method available for removal of N from wastewaters (Focht and Chang, 1975; Tchobanoglous and Burton, 1991; Furukawa et al., 1994). The effectiveness of the biological nitrogen removal process depends on the ability of nitrifying organisms to oxidize ammonium ions (NH_4^+) to nitrite (NO_2^-) and nitrate (NO_3^-). Subsequent reduction to molecular N, denitrification, is rapid with available carbonaceous substrate and an anaerobic environment, conditions that are typically found in farm settings in constructed wetlands (Rice et al., 1998) or liquid manure storage units (Bernet et al., 1996). The reaction rate of nitrification is extremely low compared to that of denitrification, so that nitrification will normally be a rate-limiting step in biological nitrogen removal process.

The basic problem related to nitrification in wastewaters with a high content of organic carbon is the low growth rate of the nitrifying bacteria; the generation time of these microorganisms is about 15 hours. Compared to heterotrophic microorganisms, which have generation times of 20-40 minutes, the nitrifiers compete poorly for limited oxygen and nutrients and tend to be overgrown or washed out of reactors (Figueroa and Silverstein, 1992; Wijffels et al., 1993). The nitrification of lagoon swine wastewater is an especially difficult process because of the very low numbers of Nitrosomonas and Nitrobacter usually found after anaerobic treatment (Blouin et al., 1990). Even when the oxygen supply is plentiful, an adaptation period is needed to reach a minimum bacteria concentration before effective nitrification. Recycling of surplus-activated sludge in an aerobic reactor or long hydraulic retention time (HRT) is required to retain slow growing autotrophic nitrifiers. Unfortunately, in the absence of enriched nitrifying populations, aerobic treatment of lagoons can potentially add to problems by stripping ammonia into the atmosphere, particularly if uncontrolled or excessive flow rates of air are used (Burton, 1992).

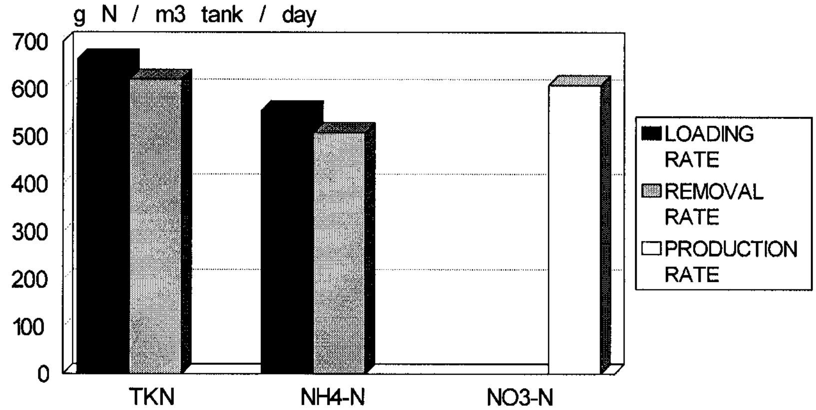
The efficiency of the nitrification process can be increased by increasing the nitrifiers retention time independent from the wastewater retention time (Wijffels et al., 1993). In most cases this is done by immobilization of nitrifiers. One advantage of this technology is that increased wastewater flow is possible with minimal washout of immobilized bacteria. Immobilization has been widely used in wastewater treatment applications by taking advantage of spontaneous attachment of cells to the surface of inert support materials. Applications of attached growth for treatment of swine wastewater have been developed by Ciaccolini et al. (1984) and St.-Arnaud et al.(1991) who reported higher nitrification rates compared to systems where microorganisms were in suspension.

Advances in biotechnology using immobilization technology have shown that higher nitrification efficiencies are possible through the entrapment of cells in polymer gels, a common technique in drug manufacturing and food processing. The successful application for nitrification treatment of municipal wastewater has been demonstrated using both natural polymers such as calcium alginate (Lewandowski et al., 1987) and synthetic polymers such as polyethylene glycol, PEG (Tanaka et al., 1991), or polyvinyl alcohol, PVA (Furukawa et al., 1994). Pellets made of synthetic polymers are superior to natural polymers in terms of strength and durability; their estimated life span is about 10 years. These characteristics are very important in long-term biotreatment operation. For this reason, synthetic polymer pellets are preferred for pilot- and plant-scale purposes. There are currently several full-scale municipal wastewater treatment plants using this technology in Japan (Takeshima et al., 1993).The nitrifiers are entrapped in 3- to 5-mm polymer pellets permeable to $NH4^+$, oxygen, and carbon dioxide needed by these microorganisms, resulting in a fast and efficient removal of N. Tanaka et al. (1991) reported nitrification rates three times higher than those of the conventional-activated sludge process.

We advanced the immobilization technology by successfully culturing acclimated lagoon nitrifying sludge (ALNS) immobilized in 3- to 5-mm polyvinyl alcohol (PVA) polymer pellets by a PVA-freezing method (Vanotti and Hunt, 2000). Swine wastewater was treated in aerated, suspended bioreactors with a 15% (w/v) pellet concentration using batch and continuous flow treatment. In batch treatment, only 14 h were needed for nitrification of NH_4^+. Ammonia was nitrified readily, decreasing at a rate of 16.1 mg NH_4-N L^{-1} h^{-1}. In contrast, it took 10 d for a control (no-pellets) aerated reactor to start nitrification; furthermore, 70% of the N was lost by air stripping. Without alkalinity supplements, the pH of the liquid fell to 6.0-6.2, and NH_4^+ oxidation stopped. In continuous flow treatment, nitrification efficiencies of 95% were obtained with NH_4^+ loading rates of 418 mg-N L-reactor^{-1} d^{-1} (2.73 g-N g-pellet^{-1} d^{-1}) and an HRT of 12 h. The rate of nitrification obtained with HRT of 4 h was 567 mg-N L^{-1} d^{-1}. In all cases, the NH_4-N removed was entirely recovered in oxidized N forms [(Vanotti et al., 1999a) (Fig. 5)].



Nitrification rates obtained in this work were comparable to rates obtained with municipal systems. This indicates that immobilized ALNS pellets were not greatly affected by high NH_4^+ or BOD concentration of swine wastewater. In fact, we have successfully run a field prototype system for over two years [(Vanotti et al., 1999b) (Fig. 6)]. Thus, immobilized pellet technology can be adapted for fast and efficient removal of NH_4^+contained in anaerobic swine lagoons using acclimated microorganisms.



One of the potentially most effective and passive methods of treating the soluble fraction of animal residuals is constructed wetlands. Wetlands have been successfully used for advanced treatment of municipal and residential wastewaters in the USA and around the world for over three decades (Kadlec and Knight, 1996). Compared to conventional systems, they have 1) less construction, operation, and energy costs and 2) more flexibility in pollutant loading. They can be built on aerated upland soils; the necessary hydric soil conditions and aquatic plant life will develop when the soils are flooded. Two types of wetlands are typically used: subsurface and water-surface-flow (Hammer, 1989). Subsurface systems are subject to clogging and limited oxygen diffusion. Consequently, research on constructed wetlands for animal waste treatment in the USA has focused on water-surface-flow systems with emergent plants (Hunt et. al., 1995; Payne Engineering and CH2M Hill, 1997).

Even though wetlands have produced some impressive treatment results, it is likely that they can be improved with better understanding of their function and optimal placement in a treatment sequence. Our treatment wetlands were constructed in Duplin Co., North Carolina, in 1992 and continue to function. They have been investigated as part of a USDA Water Quality Demonstration project. They consist of six 3.6-m x 33.5-m cells. Three systems comprised of two cells connected in series were evaluated. One set of two cells contained rush and bulrushes, and another set of two cells contained bur-reed and cattails. The third set contained soybean grown in saturated-soil culture in one cell connected to a second cell with flooded rice. Different nitrogen loading rates were obtained by dilution of wastewater with fresh water. A nitrogen loading rate of 3 kg ha^{-1} day^{-1} was used during the first year of operation, but the rate was increased up to 25 kg ha^{-1} day^{-1} in the subsequent three years. During the growing seasons with N loading <10 kg ha^{-1} day^{-1}, nitrogen reduction rates were similar between wetland plants and agronomic crops. At the low loading rate, 94% of the nitrogen was removed, but at the higher loading rates, 80 to 90% was removed [(Szogi et al., 2000) (Table 1)].

Table 1. Mass removal of N in constructed wetlands, NC, USA (June 1993-November 1997).

Nitrogen Load	System	
	Rush/bulrush	Cattails/bur-reed
kg ha^{-1} day^{-1}	Mass Removal, %	
3	94	94
8	88	86
15	85	81
25	90	84

% Mass Removal = % mass reduction of N (NH_3-N + NO_3-N) in the effluent with respect to the nutrient mass inflow.

These removal rates were much greater than can be applied to crop or pasture land. The mean above-ground dry matter production by wetland plants was 21 Mg ha^{-1} yr^{-1}. Rice grain yield was 3.7 Mg ha^{-1} yr^{-1}, and soybean yielded up to 4.3 Mg ha^{-1} yr^{-1}. The redox conditions of the wetland soils were highly reducing, generally 100 to -200 mV. These reducing conditions likely inhibited N loss by nitrification. Denitrification enzyme assays indicated that nitrate was the limiting factor for denitrification. Additionally, results of a microcosms study indicated that removal rates could likely be increased at least two-fold by pre-wetland nitrification of wastewater. In summary, saturated-soil culture soybean and flooded rice produced modest grain yields while treating wastewater for removal of N. However, they were only effective during the growing season. The wetlands with natural plants showed great promise by removing >84% of the N at an application rate of 25 kg ha^{-1} day^{-1} during the warmer eight months of the year. The wetlands were nitrate limited. Consequently, their mass N removal can be increased by nitrifying the effluent prior to wetland application if sufficient plants are present to provide carbon for denitrification (Vanotti et al., 1998). This pre-wetland nitrification will also lower both potential ammonia damage to wetland plants and volatile loss of ammonia-N. These findings are consistent with our view that improved wastewater treatment can often be achieved by sequencing wetlands in the treatment process.

It is the opinion of the authors that great benefits for animal production, carbon sequestration, and soil/crop productivity can be accomplished by the advancement of both concepts and technologies for animal residuals management. It will require a blend of innovative knowledge and techniques. There are many obvious and subtle obstacles that must be overcome. However, history has shown countless times that the solutions are found when private and public resources of the USA are focused on a problem. We are in need of pubic policies that will help focus our resources to save both our agricultural industries and environment.

References

Barker, J. C., and L. B. Driggers. 1981. Design criteria for alternative swine waste flushing systems. Amer. Soc. Agr. Eng. pp. 367-370, 374.

Bernet, N., N. Delgenes, and R. Moletta. 1996. Denitrification by anaerobic sludge in piggery wastewater. Environ. Tech. 17:293-300.

Blouin, M., J.-G. Bisaillon, R. Beaudet, and M. Ishaque. 1990. Nitrification of swine waste. Can. J. Microbiol. 36:273-278.

Burton, C. H. 1992. A review of the strategies in the aerobic treatment of pig slurry: Purpose, theory and method. J. Agric. Eng. Res. 53:249-272.

Ciaccolini, I., G. Cosmai, A. Micheli, P. Vitali, and M. Corrado. 1984. Tests of nitrification of effluents from anaerobic digestion of swine wastes with recovery of fertilizers for agricultural use. Acqua-Aria 2:145-154.

Figueroa, L. A., and J. Silverstein. 1992. The effect of particulate organic matter on biofilm nitrification. Water Environ. Res. 64:728-733.

Focht, D. D., and A. C. Chang. 1975. Nitrification and denitrification processes related to waste water treatment. Adv. Applied Microbiology 19:153-186.

Frederick, J.R., and P.J. Bauer. 1996. Winter wheat responses to surface and deep tillage on the southeastern Coastal Plain. Agron. J. 88(5):829-833.

Frederick, J. R., P. J. Bauer, W. J. Busscher, and G. S. McCutcheon. 1998. Tillage management for double cropped soybean grown in narrow and wide row width culture. Crop Sci. 38:755-762.

Furukawa, K., S. Ryu, M. Fujita, and I. Fukunaga. 1994. Nitrogen pollution leachate at a sea-based solid waste disposal site and its nitrification treatment by immobilized acclimated nitrifying sludge. J. Fermentation Bioeng. 77:413-418.

Hammer, D.A. (ed.) 1989. Constructed Wetlands for Wastewater Treatment - Municipal, Industrial, and Agricultural. Lewis Publishers, Chelsea, MI. 831 p.

Hill, D. T., and E. W. Tollner. 1980. Chemical and physical properties of flushed swine waste after screening. ASAE Paper No. 80-4056. St. Joseph, MI:ASAE.

Hunt, P.G., D.L. Karlen, T.A. Matheny, and V.L. Quisenberry. 1996. Changes in carbon content of a Norfolk loamy sand after 14 years of conservation tillage or conventional tillage. J. Soil and Water Conservation 51(3):255-258.

Hunt, P.G., Thom, W.O., Szogi, A.A. and Humenik, F.J. State of the art for animal wastewater treatment in constructed wetlands. Proc. Seventh Intl. Symp. on Agricultural and Food Processing Wastes. pp. 53-65. 1995.

Jenkinson, D.S. 1991. The Rothamsted long-term experiments: Are they still of use? Agron. Journal 83 (1):2-10.

Kadlec, R.H. and R.L. Knight.1996. Treatment Wetlands. pp. 111-112. Boca Raton: Lewis Publishers, CRC Press.

Lewandowski, Z., R. Bakke, and W. G. Characklis. 1987. Nitrification and autotrophic denitrification in calcium alginate beads. Wat. Sci. Tech. 19:175-182.

Loehr, R. C. 1973. Development and demonstration of nutrient removal from animal wastes. EPA Report R2-73-095. Washington, DC:Environmental Protection Agency.

Payne Engineering and CH2M Hill. 1997. Constructed wetlands for animal waste treatment. Report prepared for the EPA's Gulf of Mexico Program; pub. Alabama Soil and Water Conservation Committee, Montgomery, AL.

Rice, M., A. Szogi, S. Broome, F. Humenik, and P. Hunt. 1998. Constructed wetland systems for swine wastewater treatment. pp. 501-505. *In* Proc. Animal Production Systems and the Environment. Des Moines, IA:Iowa State Univ.

Sievers, D. M. 1989. Rapid mixing influences on chemical coagulation of manures. Biological Wastes 28:103-114.

Sievers, D. M., M. W. Jenner, and M. Hanna. 1994. Treatment of dilute manure wastewaters by chemical coagulation. Trans. ASAE 37:597-601.

St-Arnaud, S., J.-G. Bisaillon, and R. Beaudet. 1991. Microbiological aspects of ammonia oxidation of swine waste. Can. J. Microbiol. 37:918-923.

Szogi, A.A., P. G. Hunt, and F. J. Humenik.. 2000. Treatment of Swine Wastewater using a saturated-soil-culture soybean and flooded rice system (accepted by Trans ASAE).

Takeshima, T., K. Motegi, H. Emori, and H. Nakamura. 1993. Pegasus: An innovative high-rate BOD and nitrogen removal process for municipal wastewater. pp. 173-181. *In* Proc. 66th Annual Water Environment Federation Conf. Anaheim, CA:WEF.

Tanaka, K., M. Tada, T. Kimata, S. Harada, Y. Fujii, T. Mizuguchi, N. Mori, and H. Emori. 1991. Development of new nitrogen removal system using nitrifying bacteria immobilized in synthetic resin pellets. Water Sci. & Tech. 23:681-690.

Tchobanoglous, G., and F. L. Burton. 1991. Wastewaters Engineering: Treatment, Disposal, and Reuse. Irwin/McGraw-Hill.

Vanotti, M. B., A.A. Szogi, P.G. Hunt, F.J. Humenik, and J.M. Rice. 1988. Nitrification options for swine wastewater treatment. pp. 795-800. *In* Animal Production Systems and the Environment Conf. Proc., July 19-22, Des Moines, IA.

Vanotti, M. B. and Hunt, P. G. 2000. Nitrification treatment of swine wastewater with acclimated nitrifying sludge immobilized in polymer pellets (accepted Trans. ASAE).

Vanotti, M. B., M. Nakaoka, P. G. Hunt, A. Ellison, and S. Odamura. 1999a. Treatment of high-ammonia animal wastewater with nitrifying pellets. ASAE Paper No. 99-4092. St. Joseph, MI:ASAE.

Vanotti, M. B., P.G. Hunt, J.M. Rice, and F.J. Humenik. 1999b. Treatment of nitrogen in animal wastewater with nitrifying pellets. Proc. Water Environment Federation WEFTEC□99. Oct. 9-13, New Orleans, LA.

Wijffels, R. H., E. J. T. M. Leenen, and J. Tramper. 1993. Possibilities of nitrification with immobilized cells in waste-water treatment: Model or practical system? Wat. Sci. Tech. 27:233-240.